



**SUSTAINABLE SUPPLY CHAIN MANAGEMENT: OPTIMIZING SUPPLY
CHAINS TO REDUCE CARBON FOOTPRINTS**

Lappeenranta–Lahti University of Technology LUT

Degree Programme in Industrial Engineering and Management

Bachelor's thesis 2025

Shueb Kamal

Examiner: Associate professor, Satu Rinkinen

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Engineering Science

Industrial Engineering and Management

Shueb Kamal

Sustainable Supply Chain Management: Optimizing Supply Chains To Reduce Carbon Footprints

Bachelor's thesis 2025

50 pages, 03 figures

Examiner: Associate professor, Satu Rinkinen

Keywords: Sustainable supply chain management, Carbon footprint reduction, Green logistics, Digital transformation, Circular economy, Environmental sustainability.

Sustainable Supply Chain Management stands as an essential operational tactic that helps companies tackle climate emissions between maintaining operational effectiveness and marketplace dominance. This paper provides a complete review of supply chain optimization methods which reduce environmental effects by studying organizational best practices. The research analysis establishes three main facets of sustainable supply chain enhancement that involve environmental criteria utilization in supplier selection and procurement management along with green logistics systems and digital emission monitoring solutions. Organizations demonstrating leadership in sustainability succeed in decreasing their carbon output by integrating schemes like sustainable buying, renewable energy adoption, circular economy approaches and AI alongside blockchain and IoT technologies. Various multinational organizations apply multiple sustainability approaches simultaneously which both minimize environmental damage and improve operational performance along with brand image. The study finds important implementation challenges which involve expensive startup expenses combined with nonstandard metric systems and employee reluctance to adopt new procedures.

ACKNOWLEDGEMENTS

First of all, I want to thank my supervisor Satu Rinkinen for all the help and encouragement throughout this research.

Moreover, I wish to thank my friends and classmates for their support and spirit throughout the thesis process.

Finally, I would like to say that without my family's continued support and guidance, I simply would not have been able to finish my thesis.

Lahti

14.02.2025

Shueb Kamal

Abbreviations

SSCM	Sustainable Supply Chain Management
SCM	Supply Chain Management
ISO	International Organization for Standardization
GRI	Global Reporting Initiative
ESG	Environmental, Social, and Governance
KPMG	Klynveld Peat Marwick Goerdeler
SDG	Sustainable Development Goals
AI	Artificial Intelligence
IoT	Internet of Things
NDCs	Nationally Determined Contributions
ETS	Emissions Trading System
EU	European Union
ITC	Investment Tax Credit
CFP	Certified Financial Planner

Table of Contents

Acknowledgements.....	2
Abbreviations.....	3
1 Introduction	5
1.1 Research Background.....	5
1.2 Research Question and Approach	7
1.3 Research Method for Systematic Literature Review Process	8
2 Theoretical Background	10
2.1 Supply Chain Management (SSCM).....	10
2.2 Sustainable Supply Chain Management (SSCM)	11
2.3 Carbon Footprint in Supply Chains.....	13
2.4 Regulatory Frameworks and Sustainability Standards	15
3 Results	17
3.1 Strategies for Reducing Carbon Footprint in Supply Chains.....	17
3.2 Technological Aspects of Sustainable Supply Chains	18
3.3 Partnership with Stakeholders and Suppliers	20
3.4 Legislative Structures and Policy Rewards.....	23
3.5 Sustainable Supply Chain Practices' Advantages	26
3.6 Case Studies on Sustainable Supply Chain Practices	28
3.6.1 Food industries	29
3.6.2 Electrical or chemical industries	30
3.6.3 Energy industries	31
4. Discussion.....	33
4.1 Integration of Sustainability in Supply Chain Practices	33
4.2 Technological Innovations for Carbon Footprint Reduction	34
4.3 Collaborative Approaches and Stakeholder Engagement	34
4.4 Regulatory and Policy Frameworks	35
4.5 Challenges and Future Directions	35
5. Conclusions.....	37
References.....	38

1 Introduction

In the twenty-first century, sustainable supply chain management is unquestionably a crucial subject (Liu *et al.*, 2023). According to Grdic *et al.* (2020), sustainable supply chain management is the incorporation of social, economic, and environmental factors into every facet of the supply chain, from sourcing and product design to delivery and transportation. In recent years, corporations have been more concerned with sustainability as a result of social injustice, limited resources, and climate change (Theeraworawit & Suriyankietkaew, 2022). Recently, customers who care about the environment have been asking more from businesses, leading to a greater interest in sustainable supply chain management.

Environmental sustainability awareness in recent times has created the necessity for businesses to minimize their carbon emissions. The essential area of research is sustainable supply chain management (SSCM) because supply chains control most of the world's carbon emissions. Organizations can manage efficiency alongside competitive performance through optimally improving their supply chain procedures to decrease environmental effects.

The research goal is to examine methods which minimize carbon emissions by enhancing sustainable supply chain operation. Research findings will emerge from a systematic review of research materials to identify optimal methods in sustainable procurement combined with green logistics combined with technology-based optimization practices.

1.1 Research Background

In today's economic environment most businesses are engaged in at least one supply chain, and competitiveness is about "supply chain vs. supply chain." Therefore, how supply chains are managed is considered a key factor in gaining a competitive advantage. (Carter and Ellram, 2003; Bratic, 2011). Because supply chain management (SCM) is so important in so many domains, it has seen significant progress over the last couple of decades. Nevertheless, while the fast increase of SCM has been accompanied by growing environmental concerns regarding waste, pollution and resource depletion caused by SCM operations and activities, the latter have taken place concurrently (Giunipero *et al.*, 2008).

Since supply chain management (SCM) includes several corporate activities and procedures that directly affect the environment, such as manufacturing, distribution, and procurement, it is most closely associated with environmental consequences (Handfield *et al.*, 2005). Nowadays, the majority of businesses participate in and work within at least one supply chain. How these businesses manage their supply chains may reduce adverse environmental effects and improve environmental protection (Seuring and Muller, 2008a; Ashby *et al.*, 2012). According to Carter and Rogers (2008), SCM is therefore essential to environmental preservation. Stakeholders, consumers, and governmental organizations are calling for more ecologically friendly goods and services due to growing environmental concerns, resource shortages, and overall environmental degradation (Linton *et al.*, 2007). The increasing demands of stakeholders, consumers and regulators have forced businesses to be full responsible for their operations and business processes and have shown their moral and environmentally conscious behaviour (Ashby *et al.*, 2012).

In light of this, companies, particularly manufacturing firms, have been compelled to adapt their traditional supply chains to be more eco-friendly because of heightened expectations for environmental and social responsibility, as well as greater demands from stakeholders, customers, competitors, and regulators in general (Matos and Hall, 2007; Gimenez *et al.*, 2012). In reaction to outside demands, community pressure, competition, and regulations, the traditional supply chain has developed into a sustainable supply chain that provides more environmentally friendly good, service, and product service combinations (Sarkis *et al.*, 2010). A brief theoretical overview of supply chain management and its growing emphasis on sustainable supply networks is provided in Section 2 to help readers better grasp the study setting.

The interdisciplinary field of sustainable supply chain management (SSCM) was established to address environmental issues and to integrate sustainable initiatives into the supply chain (Linton *et al.*, 2007; Seuring and Muller, 2008a; Green *et al.*, 2012a; Carter and Easton, 2011; Tritos *et al.*, 2013; Brandenburg *et al.*, 2014; Tseng *et al.*, 2015). According to Sarkis *et al.* (2011), Sustainable supply chain management (SSCM) has been developed as a prominent issue attracting attention both from business and academia in the academic literature of operations and supply chain management. This can be observed by the rise in articles published in respectable journals in the previous 20 years, the demand for papers for several special issues on sustainable supply chain management and so on. (Jayaraman *et al.*,

2007; Krause *et al.*, 2009; Brandenburg *et al.*, 2014; Yu and Ramanathan, 2015). The SSCM issue is not just popular in academics; practitioners and industrial organizations in particular are becoming more interested in it in the hopes of improving performance and reducing adverse environmental effects (Sarkis *et al.*, 2010; Zhu *et al.*, 2012).

In order to show a logical stance on sustainability, the current environmental sustainability agenda today calls for industrial firms worldwide to acknowledge the need for environmental management and take environmental issues into account. As the emphasis on these responsibilities has grown over the past 20 years, more industrial firms have adopted the idea of sustainable supply chain management (SSCM) and started environmental projects across their supply chains. As a result, a large number of manufacturers are implementing proactive SSCM processes, offering environmentally sustainable goods and services with little adverse effects (Green *et al.*, 2012a; Taylor and Taylor, 2013). Therefore, present manufacturers make use of a range of proactive and cutting-edge techniques including eco-design (Seuring and Muller, 2008), sustainable distribution (Vachon and Klassen, 2006), sustainable production (Seuring and Gold, 2013), sustainable procurement (Zsidisin and Siferd, 2001), and investment recovery (Zhu *et al.*, 2008a). To implement these SSCM strategies successfully, all the significant supply chain participants (manufacturers, suppliers and the consumers) must unite and have a close working relationship among themselves (Carter and Easton, 2011).

1.2 Research Question and Approach

The primary research question of this thesis is:

- How may carbon footprints be reduced via the optimization of sustainable supply chain procedures?

The main research question is divided into three sub dimensions:

SQ1: Which environmental criteria used for supplier material choices, selection of sources and supply chain partners brings down carbon emissions during delivery operations?

SQ2: What role do optimize transportation networks, energy-efficient logistics, and alternative fuels play in minimizing carbon emissions across supply chain operations?

1.3 Research Method for Systematic Literature Review Process

In this thesis a systematic review of the literature is made to study ways of reducing carbon emissions and in a sustainable way manage the supply chain. The research process involved identifying, selecting, and analysing relevant academic studies, industry reports, and other credible sources.

The first stage of the procedure was to find relevant literature, searching academic databases like Google Scholar, Scopus, Web of Science and industry publications from groups such as UNCTAD and the World Economic Forum. To ensure comprehensive coverage of the topic, a combination of relevant keywords was used, including "sustainable supply chain management," "carbon footprint reduction," "green logistics," and "digitalization in supply chains."

Once the initial pool of literature was identified, a selection process was applied based on three key criteria. First, all of the studies included are only on the basis of conference papers, peer reviewed journal publications and reputable industry reports to assure legitimacy. Second, studies published within the last 10 to 15 years (2010–2024) were prioritized to maintain relevance to current industry practices and trends. Third, the selected research needed to focus explicitly on sustainability in supply chains and carbon footprint reduction to align with the thesis objectives.

Following the selection process, screening and data extraction were conducted to refine the literature further. Initially, titles and abstracts were reviewed to determine relevance. Studies that met the criteria underwent full-text analysis to extract key concepts, strategies, and trends. The extracted information was then categorized into thematic areas, including sustainable sourcing, green logistics, and energy efficiency in supply chains.

To ensure the reliability of the selected studies, a quality review was conducted based on four factors: credibility, research methodology, transparency, and consistency. Credibility was evaluated by determining whether the study was published in a peer-reviewed journal

or a recognized industry source. The research methodology was assessed to distinguish between quantitative, qualitative, and mixed-method approaches. Transparency was examined by reviewing whether the study explicitly discussed its limitations and potential biases. Finally, findings were cross-checked with other sources to ensure consistency and reliability.

The final stage involved analysing and synthesizing the collected data to identify patterns, trends, and contradictions across studies. A thematic analysis was conducted, grouping findings into categories such as digitalization in supply chains, AI-based optimization, and green logistics strategies. Additionally, gaps in existing research were identified, particularly areas where studies presented conflicting results or lacked sufficient data. This structured approach enabled a comprehensive and objective review of the existing literature, providing a strong foundation for discussing key strategies for reducing the carbon footprint in supply chains.

AI based language enhancement tools were used in different levels of the thesis writing process. ChatGPT was used for the generation of ideas and bringing initial drafts to perfection; Grammarly was used to identify and correct grammatical mistakes; while QuillBot helped to restructure sentence structures to improve clarity and flow. This made the research precise and easy to read whilst retaining the intended meaning and content of the research.

2 Theoretical Background

The chapter establishes an overview about literature related to sustainable supply chain management (SSCM) concepts. The fundamental objective of this chapter involves examining existing studies to understand concepts related to the research phenomenon. The research topic shows complex interdisciplinary and integrated characteristics which require this chapter to examine and advance key research clusters that address essential issues from the proposed investigation.

2.1 Supply Chain Management (SSCM)

This paper starts with background information about SCM since it will use SSCM terminology as the research foundation. Following this introduction there is a review of the chosen research phenomenon along theoretical lines. The integrated multidisciplinary field of supply chain management (SCM) has progressed into becoming an independent discipline according to Carter and Ellram (2003) and Storey et al. (2006). End users can acquire information goods and services from manufacturers or suppliers through an optimal logistic route which defines a supply chain says Slack et al. (2010). Organizations involved in providing services and products to end customers execute activities from multiple entities which are linked through direct or indirect relationships (Harrison, 2001). The definition of SCM adopted for this research relies on the popular version presented by Handfield and Nichols (1999, p.2) that states:

The integration of suppliers along with manufacturers together with warehouses and stores through supply chain management approaches allows the distribution of merchandise with optimal quantities delivered to correct locations at proper timeframes to achieve service level standards while lowering total system costs.

The main objective of Supply Chain Management is to handle relationships and business activities between a focal firm and its suppliers and customers to obtain low-cost efficient supply chain operation (Croxtton et al., 2001). The four essential operational areas of supply chain management (SCM) are purchasing production distribution and finance management (See Figure 1 according to the literature). The primary functions in supply chain management include purchasing and production and finance and distribution management

activities (Bratic, 2011) and the important players engage directly or indirectly with these functions which require positive relationship development to create beneficial results for all participants. The operational success and efficiency of a complete supply chain depends on how main companies and suppliers and customers address crucial activities (Storey et al., 2006).

The supply chain management (SCM) responsibilities focused primarily on a manufacturing company placed centrally within the supply chain according to Figure 1 (Croxtton et al., 2001). In accordance with existing academic literature the leading entity serving as the focus company for supply chain management (SCM) analysis stands as the manufacturer in this research (Kuik et al., 2011; Taylor and Taylor, 2013).

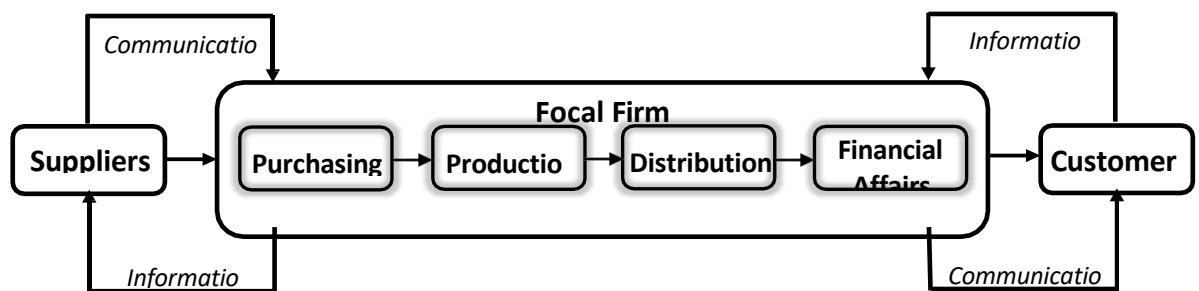


Figure 1: SCM's primary tasks (Bratic, 2011)

The purchases activity serves to acquire products or solutions that help organizations reach their targets (Lambert and Cooper, 2001) as indicated by Figure 1. According to Storey et al. (2006) purchasing activities carry out through all supply chain stages while good management techniques present opportunities for cost reduction and operational enhancement. A production activity combines immaterial elements such as plans or know-how with material components consisting of raw materials or parts to deliver end-user valuable commodity or service products (Slack et al., 2010). Productive management of production processes enhances supply chain efficiency as a whole according to Lambert et al. (1998).

2.2 Sustainable Supply Chain Management (SSCM)

The section analyzes how concepts from supply chain management (SCM) establish the basis for research phenomena before studying the concept's evolution of sustainability-related attention to establish the field of SSCM. The concept of traditional supply chain management (SCM) has evolved from operational and economic prioritization to include social and environmental factors concerning supply chain operations (Carter and Easton, 2011). Multiple comparable forces together with dynamic elements require standard supply chains to develop social and environmental awareness (Diabat and Govindan, 2011). Figure 2 shows the history of SCM becoming sustainable while showing the emergence of SSCM.

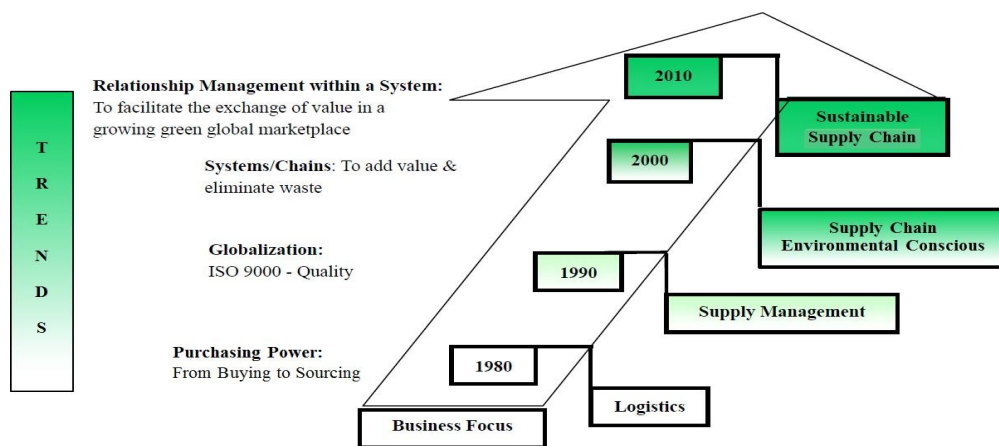


Figure 2: The revolution of supply chain sustainability (adapted from Gilbert, 2001)

After the quality and supply chain revolutions in the late 1980s, businesses began to progressively become more environmentally concerned, according to Srivastava (2007). Using command and control logic in assembly lines and machines, high-volume manufacturing was built during this time (Nahm and Vonderembse, 2002). Increase in production volume led to parallel growth of supply chain-related pollution together with solid waste and effluent waste and emissions and other environmental issues (Vonderembse et al., 1997). The conventional supply chain produced multiple environmental issues that led to acid rain as well as global warming in addition to broader adverse environmental effects (Sarkis 2006). The severe environmental problems facing policymakers and corporate entities made them enact a post-industrial strategy to merge economic performance with environmental protection (Nahm and Vonderembse, 2002).

2.3 Carbon Footprint in Supply Chains

Different methodologies determine carbon footprint assessment in supply chains because they measure emissions at varying precise accuracy thresholds and scope levels. Organizations must determine if they want to acquire broad information or need to find exact measurements during method selection. The accurate division of emissions between multiple organizations represents a significant hurdle when multiple companies combine their operations because their joint output results from integrated product development (Boukherroub et al., 2017; Caro et al., 2013; Chen and Chen, 2017). Supplier chain carbon footprint consists of all greenhouse gas emissions produced between procurement activities and through production sequences and transportation while conducting distribution. The increasing global expansion of supply networks generates escalated environmental impact that brings major carbon emissions from manufacturing operations and inadequate logistics systems along with last-mile distribution. Frameworks containing GHG Protocol and Life Cycle Assessment help organizations detect their most vital emission points which require improvement. Decarbonization efforts can be achieved through three essential strategies that include choosing eco-friendly suppliers in addition to transporting goods with different modes and utilizing alternative fuel systems. Several problems such as financial obstacles and variable reporting guidelines exist even after introducing these solutions. Strategies to control these emissions must be addressed fully to achieve climate targets alongside supply chain resilience and they establish reduced carbon footprint levels as the center of sustainable supply chain management efforts.

People around the world now view the 'carbon footprint' as a rising issue. Studies have developed a method to measure the quantity of CO₂ and other greenhouse gases released by human activities through the carbon footprint (CFP). Global warming and natural resource depletion attribute primarily to this factor. Three categories of greenhouse gas emissions exist when an organization discusses their emissions. These are:

- **Emissions directly**

It indicates how much carbon dioxide is produced or emitted into the atmosphere, as well as how much greenhouse gas is released into the environment as a direct result of various organizational activities, such the production of energy. The usage of fertilizer puts the

environment at risk because it releases nitrous oxide (N₂O) into the atmosphere. These contaminants can all be considerably reduced by employing eco-friendly methods.

- **Emissions that are indirect**

We lack direct control over this type of pollution, which refers to the products or services used or produced by a company that contribute to CO₂ emissions indirectly. An indirect emission might be defined as the quantity of CO₂ released by the business when its goods or services are moved from one place to another.

- **Electricity-related emissions**

Electricity is essential to all businesses and must be purchased from a variety of suppliers. Coal, natural gas, and nuclear power are the main energy sources in the world, while there are many others. Consequently, the firm is held accountable for this contamination even though it has no direct influence over it.

These days, companies desire to determine their CFP to sustain and lower it. Any business can leverage this as a foundation to manage carbon emissions and develop an effective environmental management system. To lower their CFP, some firms have implemented several operational and strategic reforms over the last 10 years. Several solutions to various carbon challenges related to supply chain management were studied and put forth by researchers. The "carbon trading system" is one approach that allows a company to lower its CFP commitments. In carbon cap scenarios, a traditional economic order quantity (EOQ) model is used to account for the price of carbon. Following that, companies can determine how much to order, which will assist them in managing the CFPs in their stock (Hua *et al.*, 2011). Chaabane *et al.* (2012) suggest using a mixed-integer linear program (MILP) to manage emission trading. To create a sustainable supply chain, the model outlines efficient carbon management techniques. By altering or adjusting its operational choices, an organization can lower its CO₂ emissions. Different carbon emission limits were taken into account in a single-item incapacitated lot-sizing problem by Benjaafar *et al.* (2012).

The system applied emission restrictions that applied to all product shipping processes through every means of transport. The research includes descriptions of additional emission constraints which consist of global, rolling, cumulative and periodic carbon emissions.

Creators of dynamic protocols are needed to find periodic carbon emission solutions in polynomial time (Absi et al., 2013). Pricing together with dependent environmental requirements and total carbon emissions and environmental policy serves as the foundation of the traditional EOQ model structure. This model generates alternatives suitable for different conditions that help companies earn more revenue and decrease their carbon footprint (Hovelaque and Bironneau, 2015). The carbon cap and trade system which functions in traditional and green markets can be reconstructed according to Chai et al. (2018). Companies can use the circular economy as an information-based product recovery system by analyzing both critical indicators and obstacles according to Dwivedi and Madaan (2020) and Dwivedi et al. (2020).

2.4 Regulatory Frameworks and Sustainability Standards

The sustainability reporting framework exists through multiple organizations including United Nations entities as well as the London Stock Exchange and European Union and independent groups including Global Reporting Initiative according to Carrots & Sticks. Different national laws and instruments use parts from international and sustainable reporting systems as part of their framework. Officials in approximately dozens of nations reference the GRI Standards in their governmental and marketplace texts and the standards appear among multiple normative criteria in their reporting requirements.

All this effort produced a range of frameworks and instruments that businesses could use to create their sustainability plans and reporting procedures. Numerous of them use a thorough approach, and some like the GRI Standards have gained international reputation and offer a strong set of metrics and disclosure items. Additionally, businesses can utilize guidelines that concentrate on specific concerns like greenhouse gas emissions, climate change, or how corporate operations affect forests.⁵⁶ The rise of sector-specific reporting and performance evaluation systems based on suggestions from industry trade groups further complicates matters. A sustainability report lacks both universal definition and specific content requirements as observed by UNCTAD in 2016 (Unctad, n.d.). Forbes world 100 largest listed companies presented ESG reporting to some extent, where 51 companies followed the Global Compact standards and 62 companies used Carbon Disclosure Protocol standards. Additionally, 10 companies utilized ISO 26000 while 48 organizations had other ISO certificates and 72 utilized one of the two versions of GRI Standards. The KPMG report

along with others identified 400 sustainability reporting initiatives among 64 nations in that year (Novaware, n.d.).

From 45% in 2001 to 96% in 2022, the G250, the 250 biggest businesses in the world by revenue according to the 2021 Fortune 500 ranking, improved their sustainability reporting. Additionally, according to a 2022 global sustainability reporting survey, which included the sample of N100, the percentage of material ESG topics identified by N100 companies in the sample was at 71%, and 64% of the G250 companies in the sample indicated that climate change is a risk to their business. As new laws requiring obligatory non-financial reporting obligations were implemented and embraced globally, KPMG forecast that reporting rates would keep rising. Other noteworthy results from the KPMG poll were as follows:

- Approximately 75% of businesses in the N100 and G250 were utilizing materiality assessments.
- As a result of nearly doubling the number of businesses reporting against TCFD, climate disclosure has become more consistent and comparable. Twenty percent of businesses did not disclose any connection to an external target (such as a 1.5 °C scenario), despite nearly three-quarters of them having specified their carbon objectives.
- Ten percent of businesses tracked the complete 17 SDGs, but SDG 8: Decent Work and Economic Growth along with SDG 12: Responsible Consumption and Production and SDG 13: Climate Action received the most attention from these businesses according to Gutterman (2024).

3 Results

3.1 Strategies for Reducing Carbon Footprint in Supply Chains

Enterprise-wide carbon emission mitigation requires businesses to utilize multiple strategic elements including digital solutions and operational practices and cooperation with suppliers. The beginning of sustainable procurement consists of selecting suppliers who possess environmental certification standards such as ISO 14001 and who work within specific geographic territories to reduce shipping routes. The implementation of electric or hydrogen-powered vehicles with renewable energy systems for warehouses enhances operations by making them more low-carbon. Circular economy principles show two key elements by making products more recycle-ready and creating reverse supply chains that complete product lifecycles. The combined efforts of business organizations that use industry-wide carbon-sharing platforms together with science-based target setting (SBTi) enhance the impact of shared efforts.

- Organizations should use Cost-Benefit Analysis to deploy cost-effective and performance-driven initiatives as stand-alone solutions before spending on more expensive investments.
- Suppliers and customers and regulatory bodies should participate together with the company for mutual agreement and shared responsibility.
- We should use emissions data analytics throughout our operations to audit and redesign strategies in order to achieve meeting changing goals.

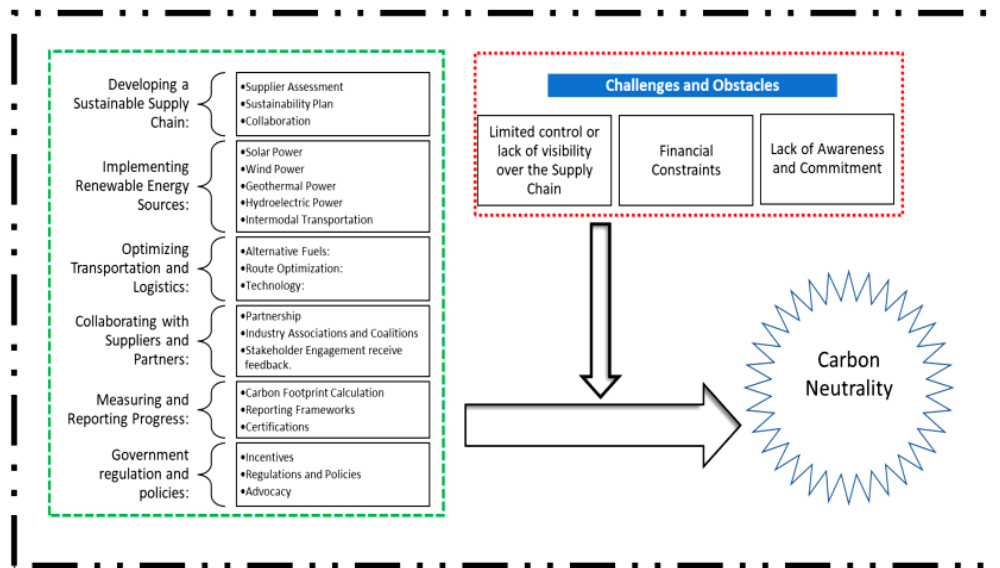


Figure 3: A framework for managing supply chains to achieve carbon neutrality: Strategies and Challenges (CNSCM) (Koh *et al.*, 2023)

3.2 Technological Aspects of Sustainable Supply Chains

Technology helps develop sustainable supply chains more and more, especially in the high impact industries of oil and gas. Such innovations as artificial intelligence (AI), blockchain and big data help making operations greener by boosting energy efficiency, boosting resource use and shining more light on emissions tracking.

Big data together with AI operate as effective tools which help enhance supply chain sustainability. Predictive analytics runs on elements from AI and Big data technology to perform real-time tracking of emissions together with energy utilization. Using AI algorithms lets companies forecast energy demand alongside emission generation in the future through combining production schedules with weather facts and equipment operational data (Abdelfattah *et al.*, 2021; Crawford *et al.*, 2023; Okeke *et al.*, 2023). The deployment of AI enables companies to conduct predictive maintenance that cuts down power losses and stops production which results in increased operational efficiency. The developed solutions enhance the organization's ability to utilize energy resources effectively throughout their refinement operations and drilling phase and transportation systems.

The supply chain needs big data systems to measure carbon emissions at every stage of operations. Organizations can identify their emission trends through the analysis of sensor and Internet of Things device and satellite monitoring data which provides an overview of their business emissions. Decision-making processes become dynamic while emissions decrease thanks to immediate problem solutions that address equipment failures which boost energy consumption (Agupugo et al., 2022, Dagunduro & Adenugba, 2020, Okeke et al., 2022, Yasemi et al., 2023). Large data analytics enables identification of unseen patterns in transactional data to discover effective carbon reduction approaches that will be beneficial for future durations.

Blockchain technology implementation helps supply chains become more sustainable in operation. Blockchain technology establishes unalterable decentralized records which provide full visibility into carbon emission data throughout its entire extraction to transportation journey (Adeniran et al., 2022, Efunniyi et al., 2022, Okeke et al., 2023, Taleghani & Santos, 2023). The forestry carbon protocol delivers both better accountability and sustainable claims management because it enables carbon offset and emissions reduction initiatives through blockchain support. Businesses benefit from Blockchain because the system supports their sustainability reporting needed to demonstrate compliance with specified carbon footprint goals while preventing cases of false environmental marketing.

It is necessary to ensure traceability in order to comply with legal requirements as well as stakeholder trust. The transparency of blockchain facilitated emissions data makes it possible to invest in emissions reduction informed and to strengthen sustainability efforts (Adenugba & Dagunduro, 2019, Elujide *et al.*, 2021, Okeke *et al.*, 2022). It can be used by companies to lay out the actions performed like the implementation of an energy efficient or renewable technology and can help it show a true commitment for environment. Blockchain also facilitates strict reporting standard that guarantees accurate and verifiable sustainability reports that increases credibility and reputation in the market.

These technologies work best when used alongside other platforms to boost sustainable supply chain performance. AI systems with IoT systems produce a combined system for continuous pollution monitoring throughout activities. System data analytics examine machinery and vehicle pollution and engine and fuel usage patterns that IoT sensors collect in order to identify performance weaknesses. The combination of these components creates advanced sustainability through an energy and emission control system.

Technology provides additional methods for including renewable energy sources within the operations of oil and gas activities. Conventionally used wind and solar energy receives enhancement through optimization from AI and big data processing. Predictive analytics supports renewable energy output optimization which reduces both fossil fuel needs alongside operational emissions according to operational requirements (Adejugbe & Adejugbe, 2020, Elujide, et al., 2021, Okeke, et al., 2023). The combination of AI and IoT Smart grids can integrate through smart APIs for guiding and saving surplus renewable power to locations requiring it and performing load management duties.

Blockchain technologies along with their recent advancements will rapidly speed up the process toward sustainable supply chain implementation. Real time emissions monitoring and energy optimization with transparency become possible through blockchain without requiring individual business system development (Adepoju & Esan, 2023, BristolAlagbariya, Ayanponle & Ogedengbe, 2023, Waswa, Kedi & Sula, 2015). The speed of market adaptation along with customer requirements and regulatory changes becomes possible through these technologies for businesses. The use of technology serves as a fundamental element for implementing green low carbon supply chains because it enables achievement of sustainability targets along with worldwide climate objectives.

In summary, supply networks are getting more sustainable through the technology like blockchain, AI, big data lowering carbon footprints. By way of improving efficiency and motivating energy use, they guarantee transparency in emissions reporting. As the need for sustainability rises and becomes more and more important, these technologies will become more important in helping companies follow rules, lower their environmental effect in an increasingly regulated world, and satisfy stakeholders.

3.3 Partnership with Stakeholders and Suppliers

It is essential to work with the suppliers and stakeholders in a lowered carbon footprint of an industry. So, sustainability is becoming a top focus that businesses need to go beyond internal operations. A cooperation that works ensures that sustainability projects have a plan to drastically cut emissions that all the actors agree with. This involves bringing the suppliers into the pitch for sustainable endeavours, instituting green procurement practices, and

working tirelessly with the locality and the local government to achieve common interests of sustainability.

A major problem is that not all the suppliers are equally committed to minimizing the environmental impact. These smaller providers or providers in areas with more relaxed environmental rules might not have the resources to sustain the practices necessary (Aniebonam *et al.*, 2023, Esan, 2023, Okeke *et al.*, 2022, Popo-Olaniyan *et al.*, 2022). But large oil and gas firms might be able to raise their clout if they make sustainability a key factor in selecting, assessing, and contracting with suppliers. Mandating suppliers to implement energy efficient production techniques, less waste and renewable forms of power is also possible.

Businesses employ green procurement as an essential method to identify low-carbon products as well as services which help minimize carbon emissions. Product evaluation requires checking three crucial factors including waste disposal and carbon emissions alongside energy usages and environmentally-friendly sourcing (Adejogbe & Adejugbe, 2016, Gil-Ozoudeh, *et al.*, 2022, Okeke *et al.*, 2023). Sophisticated procurement rules based on sustainability factors such as partner selection for sustainable operations and low-carbon technological implementation minimize oil and gas business emission production. The standards from ISO 14001 system enable organizations to achieve additional reductions in their supply chain carbon emissions. Partnerships between suppliers and their clients for manufacturing eco-friendly goods lead to advancements within low-carbon product development as well as production methods.

The oil and gas industry depends on governmental regulation and incentives combined with public policy for sustainability promotion. For sustainability to work oil and gas firms along with governments need to join forces to create laws which support sustainability practices. A few sustainability tasks involve practitioner exchanges together with rule implementation and coordinated management of climate initiatives. The adoption of carbon pricing as well as emissions taxes and Cap and trade schemes serves as policies that penalize excessive emissions and advance the use of renewable energy sources (Abdo, 2019; Bristol-Alagbariya, Ayanponle & Ogedengbe, 2022; Prauzek *et al.*, 2023). Partnerships between businesses and governments allow companies to strengthen market standings and ensure proper enforcement of climate regulation.

Oil and gas firms should approach their suppliers and stakeholders to gain access to the most recent sustainable technologies. Partnerships between suppliers and CCS technology providers allow oil and gas firms to implement carbon storage solutions and energy-saving technology (Agu et al., 2022, Gil-Ozoudeh et al., 2022, Okeke et al., 2023, Temizel et al., 2023). Academic institutions together with environmental groups can develop sustainable operation strategies with the help of partnerships between Oil and gas firms. The partnership between companies and academic institutions enables them to share environmental solutions and knowledge they possess about sustainable business practices which enhances both innovation and environmental challenge responses.

In sustainable supply chains, cooperation is also necessary to increase accountability and transparency. Exchange of data on waste management, energy consumption and emissions between oil and gas businesses and suppliers and stakeholders can help ensure that sustainability measures are properly implemented and monitored. This is because technologies like blockchain can bring about more transparency in reporting of emissions data across the supply chain (Agu *et al.*, 2022; Gil-Ozoudeh *et al.*, 2022; Okeke *et al.*, 2023; Temizel *et al.*, 2023). This enables the organizer to have the confidence of the stakeholders to pursue any efforts for the preservation of nature while maintaining the responsibilities of the corporation on that account. Stakeholders are included in sustainability projects to encourage continuous supply chain development and an accountable culture.

Supplier, stakeholder, and industry player collaboration, as applied in the oil and gas business, has a bearing on innovation, risk sharing and the acceleration of the adoption of sustainable practices and technologies as it helps to improve the business. This enables the expenses to be saved, operational effectiveness is improved, and supply network can be fortified against changes in the consumer preferences, legal requirements and market dynamics. Businesses that are considered sustainability leaderships may well gain a competitive advantage as ESG factors continue to become more important, to build their reputation and attract investment.

In conclusion, for the oil and gas supply chain to begin to lessen the carbon effect, cooperation between suppliers, local communities and governments must occur. By working together, oil and gas firms can cut their environmental footprint considerably through green procurement, and enlisting suppliers in sustainability projects. Such collaboration has led to

more sustainable supply chain that incorporate innovation, efficiency and transparency for the uptake of a low carbon future.

3.4 Legislative Structures and Policy Rewards

As the world mobilizes to respond to the adverse effects of fossil fuel extraction, transportation, and usage on environment, global and regional regulatory organizations have started exhibiting towards the advancement of sustainability and reduction of carbon emissions. When combined with legislative incentives, these rules are transforming the environment in which the oil and gas industry operates and also making a major impact on supply chain operations. At every step of the supply chain—from raw materials extraction to delivery of the finished product—they counsel creativity and effectiveness as well as environmental responsibility.

The Paris Agreement serves as an international framework that determines how nations create policies which guide their oil and gas sustainability programs. Nearly every nation maintains its membership to the Paris Agreement in order to reduce global temperatures to less than 2 °C beyond pre industrial times (1.5 °C above pre industrial times remain a target for particular countries) (Adejuge & Adejuge, 2019, Govender, et al., 2022, Okeke et al., 2022). The worldwide climate objectives together with emission reduction demands put the oil and gas sector under intense pressure to comply. All participating nations should create and maintain Nationally Determined Contributions (NDCs) which serve as emission reduction objectives under the agreement. Businesses in the industrial sector need to remain compliant with international obligations by being competitive yet following regulation standards.

In addition to the international standards, national and regional laws also affect the practices in the oil and gas supply chain. The European Union (EU) has become a leader in other efforts towards meeting environmental sustainability standards such as the European Green Deal in order to make Europe climate neutral by 2050. Another important regulation is the EU Emissions Trading System (ETS), a cap-and-trade system limiting greenhouse gas emissions in oil and gas sectors as well as allowing businesses to emit, purchase and sell their emission allowances. The approach also creates an incentive to business to reduce their

emissions to avoid having to pay additional permits or fines, and in doing so, to use more environmentally friendly supply chain practices.

The United States adopts a different stance on carbon emissions than the EU does but has constructed multiple rules aimed at lowering emission levels. Air quality standards of greenhouse gas emissions are established by the U.S. Environmental Protection Agency (EPA) (Adepoju, Esan & Akinyomi, 2022, Iwuanyanwu, et al., 2022, Okeleke et al., 2023). Methane reduction guidelines for oil and gas operations became new regulations in the United States during recent times. The New Source Performance Standards established by the EPA demands that oil and gas companies adopt technologies which reduce methane emissions during new facility and equipment repairs. The regulations promote business entities to build rules which enable them to institute procedures and technological frameworks to reduce emissions in their supply chain from extraction through transportation.

Gas and oil are themselves sectors of the economy that need to be cut, and carbon pricing is a crucial policy tool to achieve that. Under carbon taxes or the like, companies are made relevant to their carbon emissions. This "carbonizing" of business expenses forces oil and gas firms to cut their emissions to lower their exposure to these expenses.

There is one carbon pricing option that is a direct carbon tax on carbon content of fossil fuel products to raise its price and promote transition to a more eco friendly option. Nations like Canada, the UK, and Sweden have imposed carbon taxes that have been to varying degrees (Adenugba & Dagunduro, 2018, Matthews *et al.*, 2018, Orikpete, Ikemba & Ewim, 2023). These levies have a great impact on the cost structures of oil and gas supply chains, forcing companies to seek ways to lower their carbon tax debt, by switching to low carbon solutions, or modifying operations to do so.

Cap and trade systems are another way to limit emissions that, for example, the EU ETS is an example of. Here, the government sets the overall emissions cap but does this by giving credits to the companies that pollute less than their share. This system has the potential to lead to changes in the oil and gas supply chain that are beyond interfirm trading of excess allowances since it can reduce carbon emissions and may increase company profitability.

The decision-making process for oil and gas industry supply chains get significantly influenced by government regulations. The strategic decisions of organizations are directly influenced by both required adherence to regulations and the implementation of carbon

pricing systems. These business rules encourage organizations to invest funds into green procedures and innovations by offering waste reduction as well as energy efficient vehicles and renewable energy integration. Companies within the oil and gas industry automatically transition into low carbon technology adoption including CCS and renewable energy systems and biofuel generation alongside hydrogen production when operating within locations with substantial carbon pricing mechanisms.

Government incentives are a significant factor in motivating oil and gas businesses to embrace sustainable practices in addition to regulatory compliance. Such incentives are given in the form of grants, tax breaks or subsidies that encourage the creation and use of green technology. Take the example of the US government which offers tax credits to companies that set their money into renewable energy. They include wind energy's Production Tax Credit (PTC) and solar energy system's Investment Tax Credit (ITC) (Adejuge, 2021, Bristol-Alagbariya, Ayanponle & Ogedengbe, 2023, Sanyaolu *et al.*, 2023). These incentives give businesses the encouragement, or incentives, to invest in energy efficient technology or renewable energy sources to help them minimize the financial burden when making the switch to greener practices.

Oil and gas companies have to work with rules set by government. Regulations that promote accountability and transparency, for example, required emissions reporting, sustainability audits and carbon footprint labelling, impact the sector as a whole (Agupugo & Tochukwu, 2021, Nasserddine, Nasserddine & El Arid, 2023, Singh, *et al.*, 2023). For instance, by requiring them to ensure their products meet environmental criteria, the EU encourages companies to get their products from suppliers who follow similar sustainability policies.

To sum up, legislative incentives and regulatory frameworks impact greatly the oil and gas industry's carbon reduction plans. No matter what, carbon pricing schemes offer financial incentives to the companies that produce less carbon and national, regional, and international regulations provide a framework for guidance. Moreover, these rules affect supply chain strategy decisions apart from encouraging compliance with sustainability standards. Convergence of regulatory and financial constraints makes it necessary for the oil and gas sector to progressively implement greener practices to do away with its carbon emissions and environmental impact and do more to move towards a more sustainable one.

3.5 Sustainable Supply Chain Practices' Advantages

Organizations within the oil and gas sector can access various operational as well as regulatory economic and environmental advantages when executing sustainable supply chain strategies. The requirement for both governmental oversight and customer-driven carbon emission reduction continues to increase which makes sustainable practices unlock both environmental solutions and operational efficiency and regulatory compliance and competitive profits. Sustainability implementation for oil and gas companies enables them to achieve international environmental objectives and boost economic expansion and stakeholder connectivity which exceeds compliance requirements to create enduring operational value.

The most obvious advantage of using sustainable supply chain methods is the favorable effect on the environment. These tactics help corporations in achieving global emissions reduction targets in the oil and gas industry that is responsible for making major contribution to greenhouse gas emissions (Adepoju & Esan, 2023, Ning, *et al.*, 2023, Ovwigho *et al.*, 2023, Sambo *et al.*, 2023). However, in agreements regarding climate such as Paris Agreement, businesses are made responsible for their environmental impact. By adopting sustainable practices such as reducing waste, adopting energy efficient equipment, using renewable energy, shifting to better logistics, businesses will be able to cut their carbon emissions drastically. The change supports efforts aimed at curbing global climate change in line with global sustainability goals.

Ecosystems and biodiversity are also protected by sustainable supply chain methods. The loss of vital resources and the destruction of biodiversity can result from unsustainable practices like deforestation, oil spills, and inappropriate waste disposal, which can have serious and long-lasting effects on these ecosystems (Adejugbe & Adejugbe, 2018, Odulaja *et al.*, 2023, Oyedokun, 2019, Pwavodi *et al.*, 2023). Businesses may lessen their ecological footprint, stop habitat degradation, and steer clear of activities that endanger biodiversity by implementing sustainable policies that put environmental preservation first. By doing this, ecosystems are preserved and kept robust and healthy for coming generations.

Because they provide cost savings and operational efficiency, sustainable supply chain strategies are economically sound. One of the most evident advantages of sustainability is the decrease in energy prices. By adopting energy-efficient technology, such as streamlining

production processes, upgrading equipment, and switching to renewable energy sources, oil and gas firms can save a significant amount of money over time. An example is to integrate solar or wind energy into the businesses' operations, which would reduce operational expenses (Adenugba, Excel & Dagunduro, 2019, Ogbu, et al., 2023, Oyeniran, et al., 2023). Likewise, energy efficiency optimization at other stages of refining, transportation, and storage can even bring down costs, improving the economics and efficiency of the supply chain. Investments of this kind have significant long-term financial returns, especially if traditional energy costs keep rising and regulatory pressure mounts.

Another area in which sustainable supply chain practices have a positive economic impact is waste reduction. Oil and gas activities produce large volumes of waste on a regular basis including emissions, byproducts, and hazardous compounds. Implementation of waste reduction techniques such as recycling, material reuse and process optimization will reduce disposal costs and the environmental effect resulting from their business. These tactics also help diminish the requirement for the expensive environmental cleanup and waste management remediation projects.

Additionally, stakeholder trust and company reputation are improved by sustainable supply chain methods. Customers, investors, and other stakeholders are seeking more and more to support companies that put sustainability first as environmental challenges gain public consciousness. Best companies are those which show commitment to reduce environmental impact by sincere sourcing, effective resource management and honest reporting on sustainability activities, and they have much more advantages in attracting and retaining customers and investors (Adejube & Adejube, 2019, Ogbu, et al., 2023, Oyeniran, et al., 2023, Tula, et al., 2004). An assumption of positive reputation in terms of sustainability could increase market share, strengthen brand loyalty and put the company in a better competitive position in the market.

In addition to enhancing their reputation, businesses that adopt sustainable supply chain practices frequently see an improvement in their relationships with local communities and regulatory bodies. Proactive implementation of sustainable practices by oil and gas businesses can help to reduce their risk of fines, sanctions or even suspension of operations due to their noncompliance with more and more stringent rules aimed at reducing carbon emissions and protecting the environment.

Using sustainable supply chain methods give companies better chances of complying with these regulations and avoiding trouble. Champagne RJR also offers a host of waste reduction techniques, energy efficient equipment, renewable energy technologies and adoptions, which not only contributes in reducing the carbon footprint of a business, besides helping them comply with the environmental protection and emission standards. One benefit of sustainable supply chain strategy is that they adhere to environmental rules. The environment regulation for the oil and gas sector is getting stricter around the world especially in terms of resource consumption, waste management as well as carbon emission. (Abimbola & Esan, 2023, BristolAlagbariya, Ayanponle & Ogedengbe, 2022, Rane, 2023).

The compliance of environmental standards by organizations gives stakeholders from governments to investors to consumers better impressions while reducing their exposure to regulatory penalties. A business's constructive sustainability approach helps gain respect from authorities and key stakeholders while creating its reputation as an ethical enterprise. According to the research by Adland *et al.* (2019), Ogedengbe *et al.* (2023), and Oyeniran *et al.* (2022) businesses will maintain higher market adaptability and business competitiveness because environmental policy environments keep evolving.

3.6 Case Studies on Sustainable Supply Chain Practices

Multiple field research projects within sustainable supply chain management systems show different ways that manufacturing systems can decrease their environmental effects:

Nike: Sustainable supply chain management within Nike focuses on minimizing environmental effects from Nike's entire production and distribution system. A primary sustainable supply chain monitoring tool for them is the 'Considered Index.' The Considered Index program analyses product sustainability through both environmental material choice and manufacturing process sustainability.

Procter & Gamble: Procter & Gamble has launched sustainable supply chain management procedures that minimize its environmental footprint through its operations. its environmental impact. Through its program it seeks to adopt renewable energy technologies for its production locations. Procter & Gamble uses renewable energy at its factories together with Eco-friendly packaging materials to decrease waste generation during manufacturing.

Unilever: Unilever uses sustainable supply chain methods to make its production and distribution processes less damaging to the environment. The company executed a program which the company continues to lower carbon footprints during its logistics management while constructing reusable products with eco-friendly containers, recyclable and compostable.

Apple: Apple ensures sustainability from raw materials purchase all the way down to the finished goods shipped out. The organization's "Environmental Responsibility Report" shows the methodology it applies to minimize carbon emissions and conserve natural resources and fulfill waste reduction programs.

Huawei: Although there may not be any particular study on Huawei's sustainable supply chain operations, the business has made its commitment to sustainability known in the public domain. Energy conservation, sustainable packaging methods and supply chain sustainability are the key topics within the Huawei 2020 Sustainability Report. Huawei integrates sustainable practices throughout its supply chain to achieve environmental protection and employee welfare as well as sustainable business development (Ma, 2024). The conclusion demonstrates that sustainable supply chain management functions as a vital enterprise performance enhancer which brings competitive advantage benefits to companies. A variety of environmental, social and economic sustainability initiatives such as improving stakeholder satisfaction, cost savings, operational effectiveness and brand recognition can benefit businesses such as Huawei. The research's subsequent parts will examine Huawei's sustainable supply chain methods in more detail and evaluate how they affect the business's performance.

These case studies illustrate how the manufacturing and distribution activities may be reduced from environmental views by sustainable supply chain management. Businesses may improve their brand image and regulatory compliance in addition to lowering waste and their carbon footprint by putting sustainable supply chain management techniques into place.

3.6.1 Food industries

Multiple national entities together with academic bodies and organizational groups have established building sustainable food supply networks as their enduring objective.

Researchers performed multiple examinations which proved that food supply chains discharged significant quantities of greenhouse gases into the environment. The food manufacturing sector holds a significant place in the US economy despite the fact that few food businesses succeeded in building sustainable supply chains. The researchers' work enabled policymakers to determine better methods for developing sustainable food supply chains in the industry (Egilmez et al., 2014).

The model was released which consists of a multi-objective sustainable perishable food supply chain network model, two echelons and a location routing problem. Throughout the supply chain, this strategy lowers the carbon cost. In big, medium, and small challenges, hybrid approaches were found to yield superior results (Govindan *et al.*, 2014). Logistics stands as a fundamental element that drives the supply chain operations during food product distribution. Every step in the manufacturing, distribution and storage stage of food items generate considerable amounts of CFP. The selection of a top "logistic service provider" minimizes the CFP emissions in supply chain networks. Research by Kellner and Johannes (2015) proved that proper distribution of transportation and storage can achieve greenhouse gas emission reductions regardless of new technological advancements. An organization can decrease its carbon footprint effectively through changes in shipping methods within its logistical systems. The historical strategy of UK supermarket suppliers has always focused on financial revenue. According to Tidy et al. (2016) researchers found that UK supermarkets would benefit from supplier emission reduction encouragement. This paper examined how suppliers along with retailers should fulfill their social duties within supply chain networks. Environmental concerns expressed by consumers create present difficulties for traditional methods in agro-food logistics operations. Anyone who eats a regular diet pays sharper attention to food freshness in their consumption.

Food safety concerns the authorities since it poses a significant problem. To maintain supply chain sustainability businesses, work on redesigning and modifying their distribution systems. The two-stage hybrid multi objective approach serves as a research method to enhance agro food industry supply chain operations (Allaoui et al., 2018). This concept aided various managerial decisions developed for a triple bottom-line strategic approach. The research by Jiang et al. (2019) which examined a Chinese beverage industry used mixed-integer programming. Their evaluation confirmed that sustainable supply chains can adapt several operational decisions along with strategies to different degrees of uncertainty. The

sustainability of supply chain operations shows a strong dependence on minimal changes in carbon trading expenses. Scientists collected spatial greenhouse gas emission data from three important U.S. maize cultivation areas in their research (Pelton, 2019). The application of numerous nitrogen-based fertilizers led to N₂O emissions in the corn field. The study relied on a streamlined life cycle assessment approach which identified emission-prone regions together with their increased risk factors. The researchers produced results that can help businesses choose appropriate operational measures with emission reduction strategies for their policymakers.

3.6.2 Electrical or chemical industries

A sustainable supply chain formation through the "energy-climate manufacturing nexus" served as an additional research subject. Kucukvar *et al.* (2016) discovered that the sectors responsible for highest CFP emissions in the environment belonged to water and energy supply. They examined worldwide and regional supply factors to determine environmental carbon emissions and energy usage specifically for Turkish industrial businesses. The findings demonstrated that, in comparison to nations like China, the United States, and others, Turkish industrial sectors used a significant quantity of energy in 2009. They also showed that in all industrial sectors, the energy consumption is concentrated in the upstream supply chain or manufacturer's time. Future policymakers may find this study useful in understanding how various industrial sectors contribute to global warming, allowing them to modify their plans accordingly.

Data from 33 countries examining water use and electric and chemical industrial CO₂ and SO₂ emissions led to environmental impact assessments (Acquaye *et al.*, 2017). This study evaluated how to maintain operational global supply chains through extensive analysis of industry implemented measures by using 15 years of data from the multi-regional input output model. Supply chain measurements need to be properly defined according to Acquaye *et al.* (2017) to monitor progress in the future.

3.6.3 Energy industries

Various cutting-edge methods and technologies that maximize resource and energy use are necessary for sustainable development. For this reason, scientists concentrated on creating

gadgets that require less energy. In order to minimize energy costs and other resources, Sarkar *et al.* (2018) created a multi-objective sustainable supply chain model for the automotive industry. The model was solved using a weighted goal programming technique. These days, businesses prioritize employing various renewable energies in addition to reducing their energy use. In order to investigate various sustainable energy sources, researchers dedicated their expertise. The multi objective sustainable supply chain model put out by Ahmed and Sarkar (2019) incorporates the idea of carbon trading, reducing environmental damage, enhancing social responsibility, and utilizing renewable energy sources like biofuel.

The approach involved fuzzy modeling to represent variable market demand together with variable expenses. The program aimed to develop a supply chain design which would achieve environmental sustainability by decreasing carbon emissions and generating employment opportunities in renewable energy sectors. Researchers investigated logistical challenges from using renewable energy resources in their scientific study (Sadeghi and Haapala 2019). The researchers developed a mathematical model for the biomass (bio-oil) supply chain which genetic algorithms solved. The results help determine the best number of refiners, inventory warehouses and delivery trucks.

4. Discussion

This thesis identifies sustainable supply chain management (SSCM) as an essential method for greenhouse gas (GHG) reduction through its retention of operational efficiency and business competitiveness. Research findings show multiple essential supply chain emission reduction strategies and technological solutions and collaborative approaches to decrease greenhouse gas (GHG) emissions at each supply chain level. This paper examines the study results through research literature, theoretical considerations and delivers practical applications.

4.1 Integration of Sustainability in Supply Chain Practices

The traditional supply chain management practice evolves into SSCM because of both environmental limitations and economic requirements together with social considerations. According to Sarkis et al. (2010) and Carter & Rogers (2008) environmental factors receive full integration in supply chains within SSCM strategies. Organizations execute this transition because they recognize sustainability lets them gain long-term benefits including decreased costs together with better stakeholder relations and reputation enhancement (Green *et al.*, 2012a; Zhu *et al.*, 2012).

Several corporations like Unilever, Nike and Procter & Gamble demonstrate that following sustainable methods for carbon emission reduction can succeed through renewable energy adoption and waste reduction and eco-friendly material utilization. The studied cases fit within the theoretical concept of SSCM that uses the TBL framework to achieve balanced environmental, social and economic results (Seuring & Müller, 2008a). Few companies implement SSCM strategies with identical patterns since their sustainability methods are influenced by the unique industry hurdles and regulatory factors that characterize their business sector.

4.2 Technological Innovations for Carbon Footprint Reduction

The implementation of technology capabilities forms the basis for sustainable supply network operation. Digital big data tools together with blockchain systems and IoT network and AI capabilities directly engage in carbon emission and greenhouse gas management without siloed approaches. Blockchain technology delivers transparent carbon emissions tracking while enabling full accountability through its traceability solutions which also decrease possibilities of greenwashing activities (Adeniran et al., 2022; Taleghani & Santos, 2023). Through IoT technology real-time monitoring of logistics and production processes creates the ability to make dynamic changes that lower energy consumption (Okeke et al., 2023). The current technological developments match the theoretical framework of "smart sustainability" by letting digitalization activate eco-efficient processes (Liu et al., 2023). The high implementation costs as well as the shortage of skilled personnel discourage their adoption in the real world.

4.3 Collaborative Approaches and Stakeholder Engagement

The study suggests that many stakeholders, including governments, supply chain partners as well as local people should work together in order to comply with sustainability goals. The adoption of green procurement techniques along with supplier cooperation and regulatory body cooperation ensures sustainable initiative expansion in supply chains (Adejogbe & Adejogbe 2019; Gil-Ozoudeh et al. 2022). The implementation of cap-and-trade systems together with carbon pricing mechanisms coupled with governmental financing of renewable energy devices produce dual benefits by driving companies toward adopting low-carbon technologies and speeding up sustainable practice implementation (Adenugba & Dagunduro, 2018; Orikpete et al., 2023).

The adoption of sustainability practices gains support through stakeholder theory (Freeman, 1984) together with institutional theory (DiMaggio & Powell, 1983) because external regulatory measures and industry cooperation networks drive such adoption. Several continuing hurdles exist within global supply chains to develop stakeholder agreements while providing fair participation opportunities among multiple affected groups.

4.4 Regulatory and Policy Frameworks

The regulatory framework discussion showed that policies are essential in the definition of sustainable supply chains. The Paris Agreement together with the EU Emissions Trading System (ETS) provide structured mechanisms for emissions reduction according to Adejube and Adejube (2019) as well as Govender et al. (2022). A primary section of the work explores how sustainability reporting requirements become obligatory for companies while enhancing their organizational transparency and tracking performance (Gutterman, 2024). Studies suggest regulatory pressures determine unsustainable practices so organizations need to adopt sustainable methods because of the coercive properties of isomorphic influences (Diabat & Govindan, 2011). These policies measure their effectiveness through proper enforcement alongside organizational dedication to consider sustainability as their fundamental value.

4.5 Challenges and Future Directions

While this concept has been proved successful there are still number of challenges, such as financial barriers prevent small and medium sized businesses (SMEs) from adopting sustainable technologies. The inconsistent use of methods in carbon accounting makes benchmarking and progress measurement difficult for organizations (Boukherroub *et al.*, 2017; Caro *et al.*, 2013). Staff adopt a resistant attitude toward SSCM practices because organizations face an internal lag towards change and seek short-term financial benefit. The research requires analysis of digital technology scalability that spans multiple industrial environments. The development of circular economy ideas leads to zero waste supply chain development as well as the effect on business strategy of customer demand for sustainability.

This study combines multiple carbon reduction strategies which demonstrate how technology integration with team-based operation and regulatory processes enhance knowledge in SSCM. Empirical data displayed by the study enhances both resource-based view (RBV) and institutional theory by validating how sustainable practices create competitive advantage. The study delivers direct recommendations to firms wanting to lower their supply chain carbon emissions without harming their financial performance. For comprehensive supply chain change to occur the industry must sustain technological

advancements and improve policy regulations while different stakeholders demonstrate mutual commitment to sustainability.

The complexity of sustainable supply chain transformation processes is properly managed through technological integration and collaborative inter-company systems and government standards. Researchers and practitioners must utilize the provided insights to achieve sustainability targets involving climate and sustainable development activities in future SSCM projects.

5. Conclusions

Sustainable supply chain management is unquestionably a crucial subject in 21st century. The study investigates multiple methods which help supply chains decrease their total carbon emissions by implementing sustainable operational approaches. Studies for this research involved reviewing both academic papers from peer-reviewed journals alongside industrial reports from 2010 to 2024 and real-world examples from multinational corporations such as Nike and Unilever. The study looked into carbon footprint reduction strategies through sustainable supply chain management optimization whereas the main inquiry was explored by evaluating environmental criteria for supplier selection along with optimized transportation and logistics methods. All three sustainability practices used in supply chain management choosing certified suppliers from ISO 14001 standards, selecting local sources and applying circular economy principles reduces carbon emissions successfully. These include but are not limited to energy-efficient logistics, alternative fuels, and digital tools such as AI and the Internet of Things (IoT), all of which facilitate the reduction of emissions by making transport networks more economical and efficient (ex. routing) with real-time monitoring.

As well as the study underlines the necessity of sustainability achievement in supply chains by implementing participation from stakeholders and technological enhancements with proper legislative backing. Under the leadership of Unilever and Nike companies demonstrate how green procurement joined with renewable energy deployment brings both sustainability benefits and business profitability together. Businesses particularly facing challenges with expensive implementation and varying carbon accounting standards and change resistance especially affect small to medium-sized enterprises.

References

- Abdelfattah, A., et al. (2021). Predictive analytics for energy use and emissions tracking in supply chains. *Journal of Cleaner Production*, 290, 125801.
- Abdo, A. E. (2019). Development of a Well Integrity Management System for Drilling and Well Control Applications (Doctoral dissertation, Politecnico di Torino).
- Absi, N., Dauzere-Peres, S., Kedad-Sidhoum, S., Penz, B. and Rapine, C. (2013), “Lot sizing with carbon emission constraints”, *European Journal of Operational Research*, Vol. 227 No. 1, pp. 55-61.
- Acquaye, A., et al. (2017). Measuring the environmental sustainability performance of global supply chains. *Journal of Environmental Management*, 187, 571–585.
- Acquaye, A., Feng, K., Oppon, E., Salhi, S., Ibn-Mohammed, T., Genovese, A. and Hubacek, K. (2017), “Measuring the environmental sustainability performance of global supply chains: a multiregional input-output analysis for carbon, sulfur oxide, and water footprints”, *Journal of Environmental Management*, Vol. 187, pp. 571-585.
- Acquaye, A., Ibn-Mohammed, T., Genovese, A., Afrifa, G.A., Yamoah, F.A. and Oppon, E. (2018), “A quantitative model for environmentally sustainable supply chain performance measurement”, *European Journal of Operational Research*, Vol. 269 No. 1, pp. 188-205.
- Adejogbe, A., & Adejugbe, O. (2019). Carbon pricing and its impact on sustainable supply chains. *Sustainability*, 11(12), 3405.
- Adejogbe, A., Adejugbe A. (2016). A Critical Analysis of the Impact of Legal Restriction on Management and Performance of an Organization Diversifying into Nigeria. *Social Science Research Network Electronic Journal*. DOI:10.2139/ssrn.2742385
- Adejogbe, A., Adejugbe A. (2019). Constitutionalisation of Labour Law: A Nigerian Perspective. *Social Science Research Network Electronic Journal*. DOI:10.2139/ssrn.3311225
- Adeniran, A., et al. (2022). Blockchain for transparency in carbon emissions reporting. *International Journal of Production Economics*, 245, 108401.

Adepoju, O., Esan, O., & Akinyomi, O. (2022). Food security in Nigeria: enhancing workers' productivity in precision agriculture. *Journal of Digital Food, Energy & Water Systems*, 3(2).

Agu, E.E, Abhulimen A.O, Obiki-Osafiele, A.N, Osundare O.S, Adeniran I.A & Efunniyi C.P. (2022): Artificial Intelligence in African Insurance: A review of risk management and fraud prevention. *International Journal of Management & Entrepreneurship Research*, Volume 4, Issue 12, P.No.768-794, 2022.

Agupugo, C. P., & Tochukwu, M. F. C. (2021): A model to Assess the Economic Viability of Renewable Energy Microgrids: A Case Study of Imufu Nigeria.

Ahmed, W. and Sarkar, B. (2019), "Management of next-generation energy using a triple bottom line approach under a supply chain framework", *Resources, Conservation and Recycling*, Vol. 150, p. 104431.

Allaoui, H., et al. (2018). Sustainable agro-food supply chain design. *Computers and Operations Research*, 89, 369–384.

Allaoui, H., Guo, Y., Choudhary, A. and Bloemhof, J. (2018), "Sustainable agro-food supply chain design using two-stage hybrid multi-objective decision-making approach", *Computers and Operations Research*, Vol. 89, pp. 369-384.

Aniebonam, E.E., Chukwuba, K., Emeka, N. & Taylor, G. (2023). Transformational leadership and transactional leadership styles: systematic review of literature. *International Journal of Applied Research*, 9 (1): 07-15. DOI: 10.5281/zenodo.8410953. <https://intjar.com/wp-content/uploads/2023/10/Intjar-V9-I1-02-pp-07-15.pdf>

Ashby, A., Leat, M. and Hudson-Smith, M. (2012), "Making connections: a review of supply chain management and sustainability literature", *Supply Chain Management: An International Journal*, Vol. 17 Iss: 5, pp.497 - 516.

Azzola, J., Thiemann, K., & Gaucher, E. (2023). Integration of distributed acoustic sensing for real-time seismic monitoring of a geothermal field. *Geothermal Energy*, 11(1), 30.

Benjaafar, S., et al. (2012). Carbon footprint and the management of supply chains. *IEEE Transactions on Automation Science and Engineering*, 10(1), 99–116.

- Benjaafar, S., Li, Y. and Daskin, M. (2012), “Carbon footprint and the management of supply chains: insights from simple models”, *IEEE Transactions on Automation Science and Engineering*, Vol. 10 No. 1, pp. 99-116.
- Big shifts, small steps: Survey of Sustainability Reporting, KPMG International (October 2022), 9.
- Boukherroub, T., Bouchery, Y., Corbett, C., Fransoo, J., & Tan, T. (2017). Carbon footprinting in supply chains. , 4, 43-64. https://doi.org/10.1007/978-3-319-29791-0_3.
- Boukherroub, T., et al. (2017). Carbon footprinting in supply chains. *Journal of Cleaner Production*, 142, 43–64.
- Brandenburg, M., et al. (2014). Quantitative models for sustainable supply chain management. *European Journal of Operational Research*, 233(2), 299–312.
- Brandenburg, M., Govindan, K., Sarkis, J., and Seuring, S. (2014). Quantitative models for sustainable supply chain management: Developments and directions. *European Journal of Operational Research*, 233(2), pp. 299-312.
- Bratic, D. (2011), "Achieving a Competitive Advantage by SCM", *IBIMA Business Review*, pp. 1-13.
- Bristol-Alagbariya, B., Ayanponle, O. L., & Ogedengbe, D. E. (2022). Integrative HR approaches in mergers and acquisitions ensuring seamless organizational synergies. *Magna Scientia Advanced Research and Reviews*, 6(01), 078–085. Magna Scientia Advanced Research and Reviews.
- Bristol-Alagbariya, B., Ayanponle, O. L., & Ogedengbe, D. E. (2023). Frameworks for enhancing safety compliance through HR policies in the oil and gas sector. *International Journal of Scholarly Research in Multidisciplinary Studies*, 3(02), 025–033. International Journal of Scholarly Research in Multidisciplinary Studies.
- Caro, F., Corbett, C., Tan, T., & Zuidwijk, R. (2013). Double Counting in Supply Chain Carbon Footprinting. *Manuf. Serv. Oper. Manag.*, 15, 545-558. <https://doi.org/10.1287/msom.2013.0443>.

Carrots & Sticks: Global Trends in Sustainability Reporting Regulation and Policy (KPMG International, the Global Research Initiative ("GRI), the United Nations Environment Programme ("UNEP") and the Centre for Corporate Governance in Africa, 2016),

Carter, C. and Rogers, D. (2008), "A framework of sustainable supply chain management: moving toward new theory", *International Journal of Physical Distribution and Logistics Management*. Volume 38, pp. 360-387.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management. *International Journal of Physical Distribution & Logistics Management*, 38(5), 360–387.

Carter, C.R. and Easton, P.L. (2011), "Sustainable supply chain management: evolution and future directions", *International Journal of Physical Distribution & Logistics Management*, Vol. 41, No. 1, pp. 46-62.

Carter, C.R. and Ellram, L.M. (2003), "Thirty-five years of the Journal of Supply Chain Management: where have we been and where are we going?", *Journal of Supply Chain Management*, Vol. 39, No. 1, pp. 38-50.

Chaabane, A., et al. (2012). Design of sustainable supply chains under the emission trading scheme. *International Journal of Production Economics*, 135(1), 37–49.

Chaabane, A., Ramudhin, A. and Paquet, M. (2012), "Design of sustainable supply chains under the emission trading scheme", *International Journal of Production Economics*, Vol. 135 No. 1, pp. 37-49.

Chai, Q., Xiao, Z., Lai, K.H. and Zhou, G. (2018), "Can carbon cap and trade mechanism be beneficial for remanufacturing?", *International Journal of Production Economics*, Vol. 203, pp. 311-321.

challenges for geothermal energy installations monitoring: a survey. *Sensors*, 23(12), 5577.

Chen, J., & Chen, J. (2017). Supply chain carbon footprinting and responsibility allocation under emission regulations.. *Journal of environmental management*, 188, 255-267 . <https://doi.org/10.1016/j.jenvman.2016.12.006>.

Croxtan, K.L., García-Dastugue, S.J., Lambert, D.M. and Rogers, D.S. (2001), "The Supply Chain Management Processes", *The International Journal of Logistics Management*, Vol. 12, Issue: 2, pp. 13-36.

Diabat, A. and Govindan, K. (2011), "An analysis of the drivers affecting the implementation of green supply chain management", *Resources, Conservation and Recycling*, 55(6): 659-667.

Diabat, A., & Govindan, K. (2011). Drivers affecting green supply chain management implementation. *Resources, Conservation and Recycling*, 55(6), 659–667.

Dwivedi, A. and Madaan, J. (2020), "A hybrid approach for modeling the key performance indicators of information facilitated product recovery system", *Journal of Modelling in Management*.

Dwivedi, A., Agrawal, D. and Madaan, J. (2020), "Identification and prioritization of issues to implementation of information-facilitated product recovery system for a circular economy", *Modern Supply Chain Research and Applications*.

Egilmez, G., et al. (2014). Supply chain sustainability assessment of the US food manufacturing sectors. *Resources, Conservation and Recycling*, 82, 8–20.

Egilmez, G., Kucukvar, M., Tatari, O. and Bhutta, M.K.S. (2014), "Supply chain sustainability assessment of the US food manufacturing sectors: a life cycle-based Frontier approach", *Resources, Conservation and Recycling*, Vol. 82, pp. 8-20.

Esan, O. (2023). Addressing Brain Drain in the Health Sector towards Sustainable National Development in Nigeria: Way Forward.

Gilbert, S. (2001), *Greening supply chain: Enhancing competitiveness through green productivity*, Asian Productivity Organization, ISBN-10: 9283322908.

Gil-Ozoudeh, I., Iwuanyanwu, O., Okwandu, A. C., & Ike, C. S. (2022). *The role of passive design strategies in enhancing energy efficiency in green buildings*. Engineering Science & Technology Journal, Volume 3, Issue 2, December 2022, No.71-91

Gil-Ozoudeh, I., Iwuanyanwu, O., Okwandu, A. C., & Ike, C. S. (2023). *Sustainable urban design: The role of green buildings in shaping resilient cities*. International Journal of Applied Research in Social Sciences, Volume 5, Issue 10, December 2023, No. 674-692.

Gil-Ozoudeh, I., Iwuanyanwu, O., Okwandu, A. C., & Ike, C. S. (2022). *The role of passive design strategies in enhancing energy efficiency in green buildings*. *Engineering Science & Technology Journal*, Volume 3, Issue 2, December 2022, No.71-91.

Gimenez, C. Sierra, V. and Rodon, J. (2012), "Sustainable operations: Their impact on the triple bottom line", *International Journal of Production Economics*, Volume 140, Issue 1, pp. 149-159.

Giunipero, L.C., Hooker, R.E., Joseph-Matthews, S., Yoon, T.E. and Brudvig, S. (2008), "A decade of SCM literature: past, present and future implication", *Journal of Supply Chain Management*, 44(4), pp. 66-86.

Govender, P., Fashoto, S. G., Maharaj, L., Adeleke, M. A., Mbunge, E., Olamijuwon, J., ... & Okpeku, M. (2022). The application of machine learning to predict genetic relatedness using human mtDNA hypervariable region I sequences. *Plos one*, 17(2), e0263790.

Govindan, K., Jafarian, A., Khodaverdi, R. and Devika, K. (2014), "Two-echelon multiple-vehicle location–routing problem with time windows for optimization of sustainable supply chain network of perishable food", *International Journal of Production Economics*, Vol. 152, pp. 9-28.

Green, K. W., et al. (2012). Green supply chain management practices and performance. *Supply Chain Management: An International Journal*, 17(3), 290–305.

Green, K.W., Zelbst, P.J., Meacham, J. and Bhadauria, V.S. (2012a), "Green supply chain management practices: impact on performance", *Supply Chain Management: An International Journal*, Vol. 17, Issue: 3, pp. 290-305.

Gutterman, A. (2024). SDG-related reporting. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.3823833>

Gutterman, Alan, SDG-Related Reporting (May 18, 2024). Available at SSRN: <https://ssrn.com/abstract=3823833> or <http://dx.doi.org/10.2139/ssrn.3823833>.

Handfield, R., Sroufe, R. and Walton, S. (2005), "Integrating environmental management and supply chain strategies", *Business Strategy and the Environment*, Vol. 14, No. 1, pp. 1-19.

- Handfield, R.B. and Nichols, E.L. (1999), *Introduction to Supply Chain Management*, New Jersey: Prentice Hall.
- Harrison, F. (2001), *Supply Chain Management Workbook*, Routledge.
- Hovelaque, V. and Bironneau, L. (2015), "The carbon-constrained EOQ model with carbon emission dependent demand", *International Journal of Production Economics*, Vol. 164, pp. 285-291.
- Hua, G., Cheng, T.C.E. and Wang, S. (2011), "Managing carbon footprints in inventory management", *International Journal of Production Economics*, Vol. 132 No. 2, pp. 178-185.
- Iwuanyanwu, O., Gil-Ozoudeh, I., Okwandu, A. C., & Ike, C. S. (2022). *The integration of renewable energy systems in green buildings: Challenges and opportunities*. *Journal of Applied*.
- Jayaraman, V., Klassen, R. and Linton, J.D. (2007), "Supply chain management in a sustainable environment", *Journal of Operations Management*, Vol. 25, No. 6, pp. 1071-4.
- Jiang, Y., Zhao, Y., Dong, M. and Han, S. (2019), "Sustainable supply chain network design with carbon footprint consideration: a case study in China", *Mathematical Problems in Engineering*, Vol. 2019.
- Kellner, F. and Igl, J. (2015), "Greenhouse gas reduction in transport: analyzing the carbon dioxide performance of different freight forwarder networks", *Journal of Cleaner Production*, Vol. 99, pp. 177-191.
- Krause, D.R., Vachon, S. and Klassen, R.D. (2009), "Special Topic Forum on Sustainable Supply Chain Management: Introduction and Reflections on the Role of Purchasing Management", *Journal of Supply Chain Management*, Volume 45, Issue 4, pp. 18-25.
- Kucukvar, M., Cansev, B., Egilmez, G., Onat, N.C. and Samadi, H. (2016), "Energy-climatemanufacturing nexus: new insights from the regional and global supply chains of manufacturing industries", *Applied Energy*, Vol. 184, pp. 889-904.
- Kuik, S., Amer, Y., and Nagalingam, S. (2011), "Sustainable supply chain for collaborative manufacturing", *Journal of Manufacturing Technology Management*, Vol. 22, pp. 984-1001.
- Lambert, D.M. and Cooper, M.C. (2001), "Issues in Supply Chain Management," *Industrial Marketing Management*, Vol. 29, No. 1, pp. 65-83.

- Lambert, D.M., Cooper, M.C. and Pagh, J.D. (1998), "Supply chain management: implementation issues and research opportunities", *International Journal of Logistics Management*, Vol. 9, No. 2, pp. 1-19.
- Linton, D., Klassen, R. and Jayaraman, V. (2007), "Sustainable supply chains: an introduction", *Journal of Operations Management*, Volume. 25, pp. 1075-1082.
- Liu, L., et al. (2023). Leveraging digital capabilities toward a circular economy. *Computers & Industrial Engineering*, 178, 109113.
- Liu, L., Song, W. and Liu, Y., 2023. Leveraging digital capabilities toward a circular economy: Reinforcing sustainable supply chain management with Industry 4.0 technologies. *Computers & Industrial Engineering*, 178, p.109113.
- Ma, Y. (2024) The impact of sustainable supply chain management practices on business performance: A case study of Huawei. *SHS Web of Conferences*, 181, p. 03015.
- Matos, S. and Hall, J. (2007), "Integrating sustainable development in the supply chain: the case of life cycle assessment in oil and gas and agricultural biotechnology", *Journal of Operations Management*, Vol. 25, No. 6, pp.1083-1102.
- Matthews, V. O., Idaike, S. U., Noma-Osaghae, E., Okunoren, A., & Akwawa, L. (2018). Design and Construction of a Smart Wireless Access/Ignition Technique for Automobile. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 6(8), 165-173.
- Nahm, A.Y. and Vonderembse, M.A. (2002), "Theory Development: An industrial/post-industrial perspective on manufacturing". *International Journal of Production Research*, 40 (9): pp. 2067-2095.
- Nasserddine, G., Nasserddine, M., & El Arid, A. A. (2023). Internet of things integration in renewable energy Systems. In *Handbook of Research on Applications of AI, Digital Twin, and Internet of Things for Sustainable Development* (pp. 159-185). IGI Global.
- Ning, Y., Wang, L., Yu, X., & Li, J. (2023). Recent development in the decarbonization of marine and offshore engineering systems. *Ocean Engineering*, 280, 114883.
- Novaware *Carrots & sticks*. Available from : <https://www.carrotsandsticks.net/>.

- Okeke, I. C., Agu, E. E., Ejike, O. G., Ewim, C. P., & Komolafe, M. O. (2022). Modeling a national standardization policy for made-in-Nigeria products: Bridging the global competitiveness gap. *International Journal of Frontline Research in Science and Technology*, 1(2), 98–109.
- Okeke, I. C., Agu, E. E., Ejike, O. G., Ewim, C. P., & Komolafe, M. O. (2022). A theoretical model for standardized taxation of Nigeria's informal sector: A pathway to compliance. *International Journal of Frontline Research in Science and Technology*, 1(2), 83–97.
- Okeke, O., et al. (2023). IoT and AI for sustainable supply chain optimization. *Journal of Cleaner Production*, 382, 135200.
- Okeleke, P. A., Ajiga, D., Folorunsho, S. O., & Ezeigweneme, C. (2023). Leveraging big data to inform strategic decision making in software development.
- Orikpete, O. F., Ikemba, S., & Ewim, D. R. E. (2023). Integration of renewable energy technologies in smart building design for enhanced energy efficiency and self-sufficiency. *The Journal of Engineering and Exact Sciences*, 9(9), 16423-01e.
- Ovwigho, E. M., Almomen, M. S., Corona, M., & Terrez, J. (2023, March). Well Integrity Challenges while Drilling in High Pressure and Narrow Window Environment: A Case Study of a Deep Gas Field in the Middle East. In *SPE Middle East Oil and Gas Show and Conference* (p. D021S051R003). SPE.
- Pelton, R. (2019), "Spatial greenhouse gas emissions from US county corn production", *The International Journal of Life Cycle Assessment*, Vol. 24 No. 1, pp. 12-25.
- Popo-Olaniyan, O., James, O. O., Udeh, C. A., Daraojimba, R. E., & Ogedengbe, D. E. (2022). Future-Proofing human resources in the US with AI: A review of trends and implications. *International Journal of Management & Entrepreneurship Research*, 4(12), 641-658.
- Prauzek, M., Kucova, T., Konecny, J., Adamikova, M., Gaiova, K., Mikus, M., ... & Koziorek, J. (2023). Iot sensor
- Sadeghi, J. and Haapala, K.R. (2019), "Optimizing a sustainable logistics problem in a renewable energy network using a genetic algorithm", *Opsearch*, Vol. 56 No. 1, pp. 73-90.

- Sambo, C., Liu, N., Shaibu, R., Ahmed, A. A., & Hashish, R. G. (2023). A technical review of CO₂ for enhanced oil recovery in unconventional oil reservoirs. *Geoenergy Science and Engineering*, 221, 111185.
- Sanyaolu, T. O., Adeleke, A. G., Efunniyi, C. P., Akwawa, L. A., & Azubuko, C. F. (2023). Data migration strategies in mergers and acquisitions: A case study of banking sector. *Computer Science & IT Research Journal P-ISSN*, 2709- 0043.
- Sanyaolu, T. O., Adeleke, A. G., Efunniyi, C. P., Akwawa, L. A., & Azubuko, C. F. (2023). Stakeholder management in IT development projects: Balancing expectations and deliverables. *International Journal of Management & Entrepreneurship Research P-ISSN*, 2664-3588.
- Sarkar, B., Omair, M. and Choi, S.B. (2018), “A multi-objective optimization of energy, economic, and carbon emission in a production model under sustainable supply chain management”, *Applied Sciences*, Vol. 8 No. 10, p. 1744.
- Koh, S. L., Jia, F., Gong, Y., Zheng, X., & Dolgui, A. (2023). Achieving carbon neutrality via supply chain management: position paper and editorial for IJPR special issue. *International Journal of Production Research*, 61(18), 6081-6092.
- Sarkis, J. (2006), *Greening the Supply Chain*, Springer, London.
- Sarkis, J., et al. (2010). Stakeholder pressure and the adoption of environmental practices. *Journal of Operations Management*, 28(2), 163–176.
- Sarkis, J., Gonzalez-Torre, P. and Adenso-Diaz, B. (2010), “Stakeholder Pressure and the Adoption of Environmental Practices: The Mediating Effect of Training” *Journal of Operations Management*, Volume 28, Issue 2, pp. 163-176.
- Sarkis, J., Zhu, Q. and Lai, K.H. (2011), "An organizational theoretic review of green supply chain management literature", *International Journal of Production Economics*, Vol. 130 (1), pp. 1-15.
- Seuring, S. and Gold, S. (2013), “Sustainability management beyond corporate boundaries”, *Journal of Cleaner Production*, 56, pp. 1-6.

- Seuring, S. and Muller, M. (2008a), "From a literature review to a conceptual framework for sustainable supply chain management", *Journal of Cleaner Production*, Vol. 16, No. 15, pp. 1699-710.
- Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, 16(15), 1699–1710.
- Seuring, S., and Muller, M. (2008), "Core issues in sustainable supply chain management - A Delphi study", *Business Strategy and the Environment*, 17(8), pp. 455-466.
- Singh, H., Li, C., Cheng, P., Wang, X., Hao, G., & Liu, Q. (2023). Automated real-time formation evaluation from cuttings and drilling data analysis: State of the art. *Advances in Geo-Energy Research*, 8(1).
- Slack, N., Chambers, S. and Johnston, R. (2010), *Operations Management (6th Ed)*, Financial Times/Prentice Hall.
- Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, 9(1), 53–80.
- Srivastava, S.M. (2007), "Green supply-chain management: A state-of-the-art literature review", *International Journal of Management Reviews*, Volume 9, Issue 1, pp. 53-80.
- Storey, J., Emberson, C., Godsell, J., and Harrison, A. (2006), "Supply chain management: theory, practice and future challenges", *International Journal of Operations & Production Management*, Vol. 26, Issue: 7, pp.754-774.
- Sverko Grdic, Z., Krstinic Nizic, M. and Rudan, E., 2020. Circular economy concept in the context of economic development in EU countries. *Sustainability*, 12(7), p.3060.
- Taleghani, M., & Santos, R. (2023). Blockchain for carbon emissions traceability. *Sustainability*, 15(4), 3200.
- Taylor, A. and Taylor, M. (2013), "Antecedents of effective performance measurement system implementation: an empirical study of UK manufacturing firms", *International Journal of Production Research*, Vol. 51, No. 18, pp. 5485-5498.
- Temizel, C., Aydin, H., Hosgor, F. B., Yegin, C., & Kabir, C. S. (2023). Green Energy Sources Reduce Carbon Footprint of Oil & Gas Industry Processes: A Review. *Journal of Energy and Power Technology*, 5(1), 1-25.

- Theeraworawit, M., Suriyankietkaew, S. and Hallinger, P., 2022. Sustainable supply chain management in a circular economy: a bibliometric review. *Sustainability*, 14(15), p.9304.
- Tidy, M., Wang, X. and Hall, M. (2016), "The role of Supplier Relationship Management in reducing Greenhouse Gas emissions from food supply chains: supplier engagement in the UK supermarket sector", *Journal of Cleaner Production*, Vol. 112, pp. 3294-3305.
- Tritos, L., Adebajo, D. and Tan, k.C. (2013),"Green supply chain management practices and performance", *Industrial Management & Data Systems*, Volume 113, Issue 8, pp. 1088-1109.
- Tseng, M. L., Lim. M. and Wong, W.P. (2015), "Sustainable supply chain management", *Industrial Management & Data Systems*, Volume 115, Issue: 3, pp. 436-461.
- Unctad *UNCTAD DGFF2016 SDG Goal 12.6 - Sustainable company practice*. [Online] UNCTAD DGFF 2016. Available from: https://stats.unctad.org/Dgff2016/planet/goal12/target_12_6.html.
- Vachon, S. and Klassen, R.D. (2006), "Extending green practices across the supply chain: the impact of upstream integration", *International Journal of Operations & Production Management*, Vol. 26, No. 7, pp. 795-821.
- Vonderembse, M.A., Rangunathan, T.S., and Rao, S.S., (1997), "A post-industrial paradigm: To integrate and automate manufacturing", *International Journal of Production Research*, Volume 35, pp. 2579-2599.
- Yu, W. and Ramanathan, R. (2015), "An empirical examination of stakeholder pressures, green operations practices and environmental performance", *International Journal of Production Research*, 53(21), pp. 6390-6407.
- Zhu, Q., et al. (2012). Examining the effects of green supply chain management practices. *International Journal of Production Research*, 50(5), 1377–1394.
- Zhu, Q., Sarkis, J. and Lai, K. (2008a), "Confirmation of a measurement model for green supply chain management practices implementation", *International Journal of Production Economics*, Volume. 111, No. 2, pp. 261-273.

Zhu, Q., Sarkis, J. and Lai, K.H. (2012), "Examining the effects of green supply chain management practices and their mediations on performance improvements", *International Journal of Production Research*, Vol. 50, No. 5, pp. 1377-1394.

Zsidisin, G.A. and Siferd, S.P. (2001), "Environmental purchasing: a framework for theory development", *European Journal of Purchasing & Supply Management*, Vol. 7, pp. 61-73.